U.S. DEPARTMENT OF ENERGY

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WASTE PACKAGE PLAN

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YUCCA MOUNTAIN PROJECT

WASTE PACKAGE PLAN

JULY 1990

Prepared by

U.S. Department of Energy
Yucca Mountain Project Office

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FOREWORD

The Waste Package Plan describes the waste package program of the Yucca Mountain Project and establishes the technical approach for design of a waste package and associated Engineered Barrier System (EBS) components that can meet regulatory requirements.

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Note: This corrected title page replaces the previous title page which was approved on 8/13/90.

EXECUTIVE SUMMARY

The purpose of this plan is to describe the waste package program of the Yucca Mountain Project (Project) and to establish the technical approach against which overall progress can be measured. This plan provides guidance for execution and describes the essential elements of the program, including the objectives, technical plan, and management approach. The work described in this plan covers the time period up to the submission of a repository license application to the U.S. Nuclear Regulatory Commission (NRC). This plan will be revised as necessary to accommodate changes in the Yucca Mountain Project Office (Project Office) or the Office of Civilian Radioactive Waste Management (OCRWM) and their plans and procedures. This plan is a Project Office-controlled document and changes to it shall be controlled in accordance with applicable Project Office procedures.

The goal of the Project waste package program is to develop, assess the effectiveness of, and document a design for a waste package and associated EBS for spent fuel and solidified high-level waste (HLW) that meets the applicable regulatory requirements for a geologic repository.

The technical objective of the Project waste package program is to design a waste package and associated EBS components that can meet the regulatory requirements with sufficient margin for uncertainty. The design will continue to evolve as data from site characterization are obtained and as more detailed phases of design are completed. Inputs to the waste package design include regulatory requirements; interpretations of regulatory terms and design goals; and information on site and near-field environment characterizations, waste form characterization, repository design, and near- and far-field scenarios. These inputs, along with waste package materials testing and characterization and model development activities, are used to develop designs. The performance of the designs is then assessed to determine whether regulatory requirements will be met. This process is intended to result in sufficient evidence so the NRC can determine, during the licensing proceedings, that there is "reasonable assurance" that the requirements will be met.

Major milestones in the current OCRWM baseline schedule and the Project schedule are provided. The three OCRWM milestones that pertain directly to the work described in this plan are (1) start of waste package advanced conceptual design (ACD), (2) start of waste package license application design (LAD), and (3) submission of the repository license application to the NRC. The design of the waste package and associated EBS will be developed in three phases, to be consistent with the OCRWM milestones. These phases are (1) pre-ACD, (2) ACD, and (3) LAD. During each phase, designs will be developed based on the requirements and the documented technical data (waste form characteristics, near-field environment, and container and EBS materials properties). The pre-ACD phase will focus on first defining the requirements and then identifying feasible design options. These design options will be developed more fully and evaluated during the ACD phase, which culminates in the selection of preferred design options. Prototype fabrication and testing of waste package components will also be completed during the ACD phase. The

LAD phase will develop a detailed design of the preferred option and an analysis to verify that all requirements are satisfied. Because the final design analyses of the waste package and associated EBS depend on information that will be obtained from both surface-based testing and the underground Exploratory Shaft Facility (ESF), the milestones associated with these aspects of the Project are linked to the design of the waste package and EBS. A final documentation package will be prepared as input for the license application.

Subpart G of 10 CFR 60 requires that all information relating to the design, design analysis, testing, and performance assessment of the waste package and EBS that will form a basis of the license application must be acquired or developed under an NQA-1 quality assurance program based on the criteria of Appendix B of 10 CFR 50. To this end, all Participants in the Project have developed or adopted Quality Assurance Program Plans (QAPPs) that reflect all requirements of the Project Quality Assurance Plan. In the case of the waste package and EBS work, the requirements of the QAPP are being implemented through a system of quality procedures (QPs). The QAPP and QPs are supplemented by a Software Quality Assurance Plan (SQAP) that specifically addresses the implementation of the requirements of the QAPP to computer software. The QAPP, QPs, and SQAP governing the waste package and EBS program are those developed and used by the Lawrence Livermore National Laboratory.

This plan also includes a discussion of the risks associated with the program, the management hierarchy, and other management issues, such as resource planning, scheduling, and acquisition strategy.

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1.0 INTRODUCTION

The purpose of this plan is to describe the waste package program of the Project and to establish the technical approach against which overall progress can be measured. It provides guidance for program execution and describes the essential elements of the program, including the objectives, the technical plan, and the management approach. The work described in this plan covers the time period up to the submission of a repository license application to the NRC. This plan will be revised as necessary to accommodate changes in the Project Office or the OCRWM and their plans and procedures. This plan is a Project Office-controlled document, and changes to it shall be controlled in accordance with applicable Project Office procedures.

2.0 MISSION NEED AND OBJECTIVES

The goal of the Project waste package program is to develop, confirm the effectiveness of, and document a design for a waste package and associated EBS for spent nuclear fuel and solidified HLW that meets the applicable regulatory requirements for a geologic repository.

2.1 SOURCE OF MISSION

The Nuclear Waste Policy Act of 1982 (Public Law 97-425) (hereafter referred to as the NWPA) established a national effort to develop a repository for the permanent disposal of spent fuel and HLW. In passing the NWPA, the Congress charged the U.S. Department of Energy (DOE) with the responsibility for the siting, construction, and operation of such a repository. The NWPA charged the U.S. Environmental Protection Agency (EPA) with the promulgation of standards intended to protect the environment from offsite releases of radioactive material from a repository. These standards are specified in Title 40 of the Code of Federal Regulations (CFR), Part 191 (40 CFR 191).[1] The NWPA charged the NRC with promulgating the technical requirements necessary to license all phases of repository operation. These technical requirements are specified in Title 10 of the Code of Federal Regulations, Part 60 (10 CFR 60). In 1987, the NWPA was amended by the Nuclear Waste Policy Amendments Act of 1987 (Public Law 100-203), in which the Congress directed that all efforts toward the characterization of a repository site be focused on a candidate site at Yucca Mountain, Nevada.

The NWPA implicitly recognizes the need for a waste package program by requiring a discussion of the "possible form or packaging" for the HLW and spent fuel in both the Site Characterization Plan (SCP) and the DOE Secretary's recommendation for site approval to the President. The NWPA does not mandate specific objectives or function to either the waste package or EBS, though it provides the definition of both terms. Specific technical requirements for the waste package and EBS specified by 10 CFR 60 are discussed in the following sections.

2.2 OBJECTIVES

2.2.1 TECHNICAL OBJECTIVES

The technical objective of the Project waste package program is to develop a waste package and associated EBS that can meet these regulatory requirements in a way that compliance with the regulations can be

1. The First Circuit U.S. Court of Appeals has vacated and remanded Subpart B of 40 CFR 191 to the EPA for further consideration and proceedings. Any changes made by the EPA to its standards will be evaluated by the DOE to ensure that its design program will be adequate. Until changes, if any, are implemented in the EPA standards, the DOE is proceeding on the basis of the standards published on September 19, 1985.

demonstrated in a repository licensing proceeding before the NRC. The NRC rule 10 CFR 60.113 mandates two specific performance objectives for the waste package and EBS after the closure of the repository and divides the postclosure period into two time periods, conventionally referred to as the "containment" and "controlled-release" periods. The containment requirement applies primarily to the waste packages, and the controlled-release requirement applies primarily to the EBS:

Containment [10 CFR 60.113 (a) (1) (ii) (A)]

> . . . the engineered barrier system shall be designed, assuming anticipated processes and events, so that: Containment of HLW within the waste packages will be substantially complete for a period to be determined by the Commission taking into account the factors specified in 60.113(b) provided, that such period shall be not less than 300 years nor more than 1,000 years after the permanent closure of the repository.

Controlled Release [10 CFR 60.113 (a) (1) (ii) (B)]

> . . . the engineered barrier system shall be designed, assuming anticipated processes and events, so that: . . . The release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission; provided, that this requirement does not apply to any radionuclide which is released at a rate of less than 0.1% of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000 per year of the inventory of radioactive waste, originally emplaced in the underground facility, that remains after 1,000 years of radioactive decay.

The requirements relating to postclosure performance of the total repository system [10 CFR 60.112] place additional requirements on the design and performance of the waste package and EBS as follows:

> The geologic setting and the engineered barrier system and the shafts, boreholes and their seals shall be designed to assure that releases of radioactive materials to the accessible environment following permanent closure conform to such generally applicable standards for radioactivity as may have been established by the Environmental Protection Agency with respect to both anticipated processes and events and unanticipated processes and events.

A fourth major objective is to perform a "comparative evaluation of alternatives to the major design features that are important to waste isolation, with particular attention to the alternatives that would provide longer radionuclide containment and isolation" [10 CFR 60.21 (c) (1) (ii) (D)].

There are a number of other requirements that apply to the waste package and EBS prior to the permanent closure of the repository. These requirements include radiological protection [10 CFR 60.111 (a)], retrievability [10 CFR 60-111 (b)], and geologic repository operations area design criteria [10 CFR 60.131].

Finally, 10 CFR 60.135 sets forth specific design criteria for the waste package and its components that must be met. These criteria include constraints on the general performance of the package, its chemical reactivity, and provisions for its handling and labeling, as well as design criteria for the waste forms.

2.2.2 SCHEDULE OBJECTIVES

Major key programmatic milestones for the work described in this plan include the following:

- Obtain repository horizon core from surface-based testing: 1/92
- Complete pre-ACD phase: 9/92
- Obtain repository horizon materials from ESF drifts: 6/94
- Complete ACD phase: 5/96
- Complete ESF EBS test setup and start EBS tests: 9/96
- Complete LAD phase: 9/01
- Submit repository license application to NRC: 10/01

In addition to these milestones, intermediate lower-level milestones for the waste package program are listed in Section 7 and in Appendix A. Section 3, Technical Plan, provides additional discussions of all milestones.

2.2.3 QUALITY OBJECTIVES

All information relating to the design, design analysis, testing, and performance assessment of the waste package and EBS that will form a basis of the license application will be acquired or developed under an NQA-1 quality assurance program based on the criteria of Appendix B of 10 CFR 50. To this end, all Participants in the Project have developed or adopted QAPPs that reflect all requirements of the Project Office Quality Assurance Plan, which incorporates the provisions of the OCRWM Quality Assurance Requirements (QAR). In the case of the waste package and EBS work, the requirements of the QAPP are being implemented through a system of QPs. The QAPP and QPs are supplemented by a SQAP that specifically addresses the implementation of the requirements of the QAPP to computer software. The QAPP, QPs, and SQAP governing the waste package program are those developed and used by the Lawrence Livermore National Laboratory (LLNL); (Project QAPP, LLNL; Project Quality Procedures Manual, LLNL; Project SQAP, LLNL).

The QPs prescribe the methods used to control scientific investigations, testing activities, design activities, and performance assessments that are described in the technical planning sections of this plan. For example, the QPs describe how scientific investigations and design analyses are planned, controlled, and documented. They also describe which types of documents are quality assurance records and how these records are created, maintained, and stored. They describe how documents are reviewed and how the information in the documents is verified.

3.0 TECHNICAL PLAN

3.1 DESCRIPTION OF BOUNDARIES OF THE WASTE PACKAGE PROGRAM

3.1.1 DEFINITIONS

3.1.1.1 Waste package

The waste package is the "primary container that holds, and is in contact with, solidified high-level radioactive waste, spent nuclear fuel, or other radioactive materials, and any overpacks that are emplaced at a repository" [NWPA Sec. 2 (10)]. For the purposes of this plan, the 10 CFR 60.2 definition of waste package will be used, which extends this definition of a waste package to include the waste forms: "the waste form and any containers, shielding, packing and other absorbent materials immediately surrounding an individual waste container".

3.1.1.2 Engineered barrier system (EBS)

An engineered barrier system is the "manmade components of a disposal system designed to prevent the release of radionuclides into the geologic medium involved. Such a term includes the high-level radioactive waste form, high-level radioactive waste canisters, and other materials placed over and around such canisters" [NWPA Sec. 2 (11)]. The NRC rule 10 CFR 60.2 defines the engineered barrier system "the waste packages and the underground facility." The latter means the "underground structure, including openings and backfill materials, but excluding shafts, boreholes, and their seals." The 10 CFR 60.2 definition will be used in this plan with the interpretation that the excluded "boreholes" refers only to the exploratory boreholes from the surface-based testing program. The boundary of the EBS is used in this plan as coinciding with the surfaces of the underground repository drifts and emplacement boreholes.

3.1.1.3 Near field

The term near field refers to the underground geologic media that immediately surround the emplaced waste containers. An illustration of this definition is given in Section 3.1.2 and Figures 1 and 2.

3.1.2 WASTE PACKAGE PROGRAM PHYSICAL ELEMENTS

The physical elements addressed by the waste package program are illustrated in Figure 1. This figure shows a waste container emplaced in a vertical borehole with an air gap between the waste container and the wall of the borehole. A partial liner is shown and will be used as a guide to assist in the initial waste container emplacement operations. The shield plug resides above the waste container and within the partial liner. A cover is used to close the borehole at the surface of the underground repository drift floor. This figure illustrates how the waste package program must address portions of the repository EBS and near-field environment.

Boundary for Waste Package Program

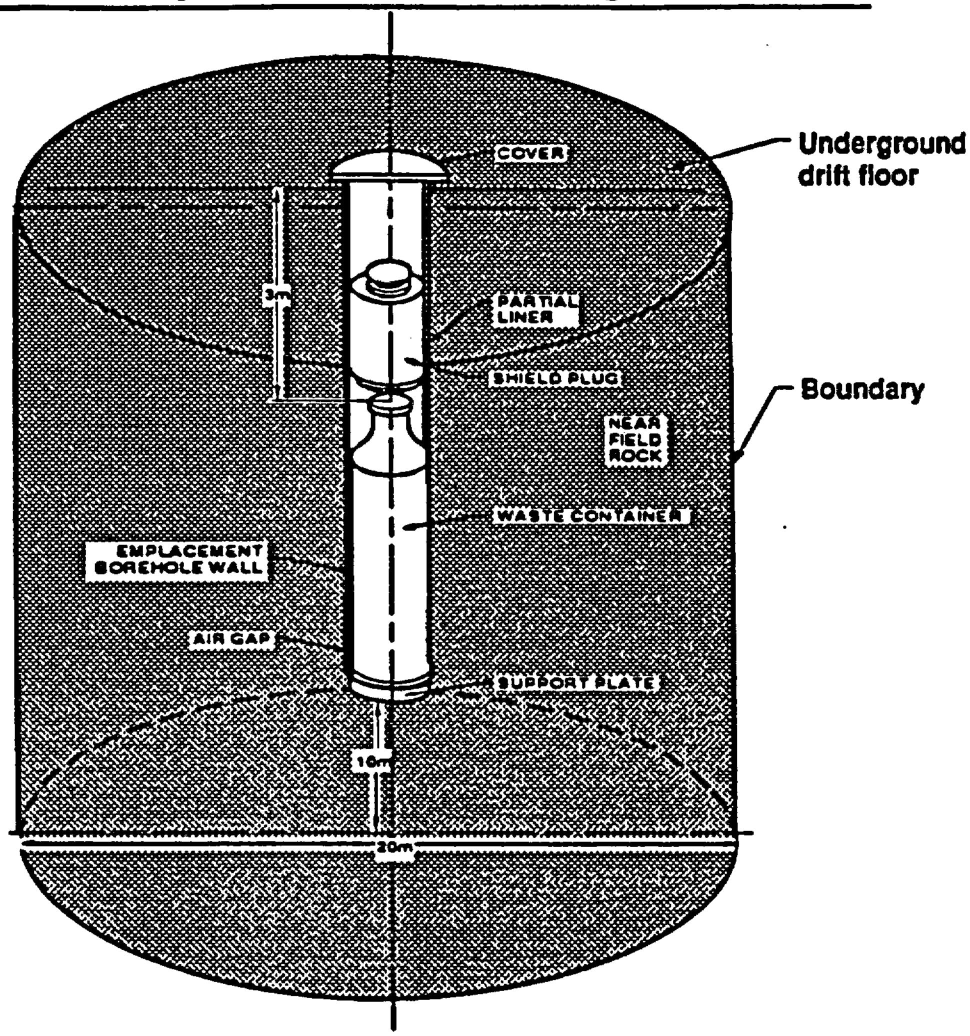
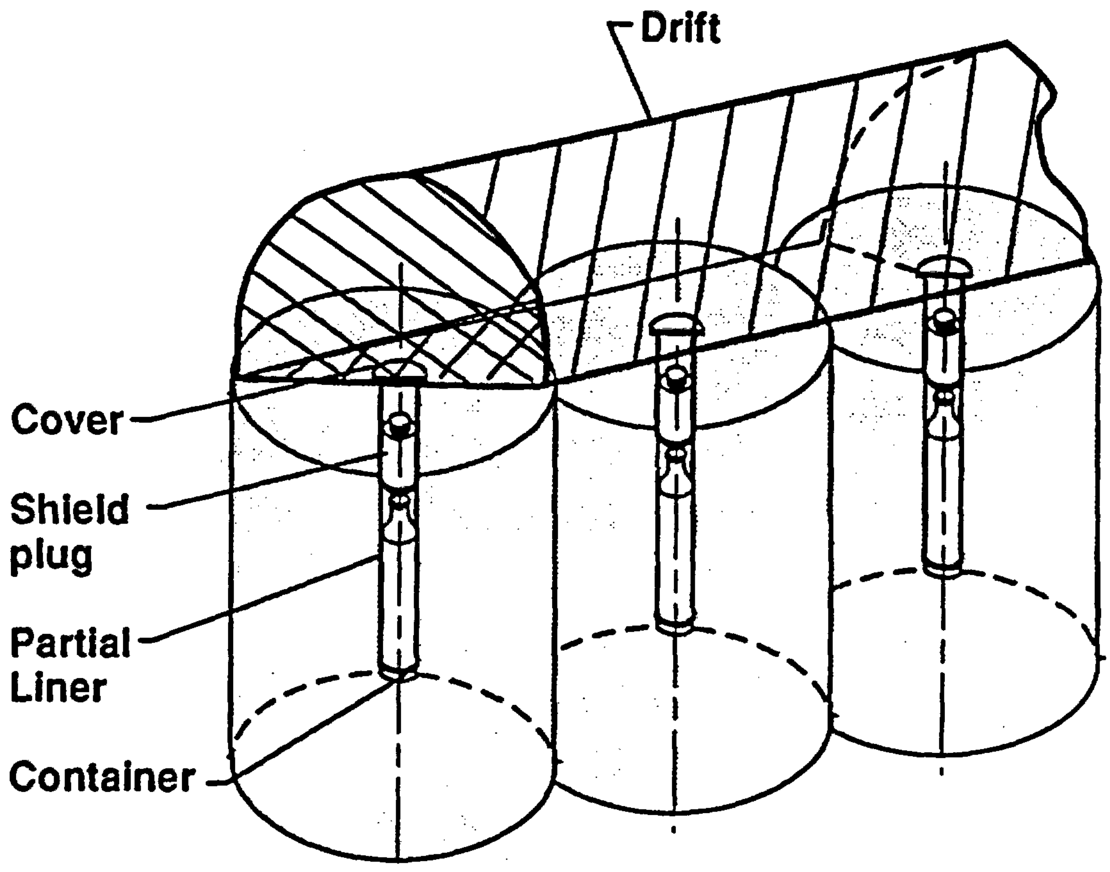


Figure 1. Ilustration of conceptual waste package and portions of the EBS.

Figure 2. Illustration of the relationship of overlapping near-field environments between individual waste packages in vertical emplacement boreholes.



The near-field environment is critically important to the design and performance of the waste package and the EBS. The near field extends beyond the boundary of the emplacement borehole as illustrated in Figure 1. Figure 1 illustrates a near field that is bounded by an imaginary cylinder having a nominal diameter of 20 meters and a centerline that coincides with the centerline of the waste container. The upper planar surface of this cylindrical boundary coincides with the floor of the drift while the lower bounding planar surface is perpendicular to the centerline of the waste container and 10 meters below the container's lower surface.

The precise shape of the near-field boundary depends upon the specific process or attribute, such as stress, temperature, and hydrologic conditions requiring characterization, and upon the time after waste emplacement. For example, the near-field stresses and radiation fields requiring characterization that are induced into the geologic media from emplaced waste forms will extend radially, only a meter or so from the borehole wall and only slightly above and below the waste container. In contrast, the hydrologic boundary for saturation requiring characterization may extend up to tens of meters radially as well as above and below the emplaced waste containers for the first several hundred years after waste emplacement. In general, the near-field environment requiring site-specific characterization will include major portions of the geologic media between emplaced waste containers and between emplacement drifts, as well as both below and above the containers and the drifts. Figure 2 illustrates the overlapping of the near-field boundaries. These boundaries are subject to further review and change as appropriate, however. It is essential that a boundary be identified in order to establish programmatic responsibilities, ensure that the required tasks are completed, and ensure that interfacing activities are properly coordinated. This plan uses the boundary in Figure 1 to establish programmatic responsibilities.

The near-field properties must include the effects of both the natural and the man-made features (such as the shield plug and borehole liners as used in Figure 1) that impact the behavior of the container and waste forms in the repository. The near-field environment of an individual waste package will be influenced by neighboring packages. Thus, to fully define the conditions to which each waste package will be exposed, emplacement borehole spacings and other design details of the repository and EBS layouts are needed. Figure 2 illustrates these relationships for several vertically emplaced waste containers.

The near-field properties of interest include the mechanical properties of the rock; the pre- and postemplacement hydrology of the area surrounding the waste packages; the thermal field around the waste packages; the chemical properties of the air, water vapor, and liquid water in the area around the waste packages; and the effects of the emplaced waste's radiation field on the near-field properties.

Figure 3 illustrates additional details of the waste containers that contain the spent fuel and the high-level waste. As shown, the waste container for the spent fuel is 187.5 inches (476 cm) long versus 129 inches (328 cm) for the high-level waste. With this one exception, the waste containers are expected to be physically identical and will be fabricated from identical materials using the same manufacturing processes, quality

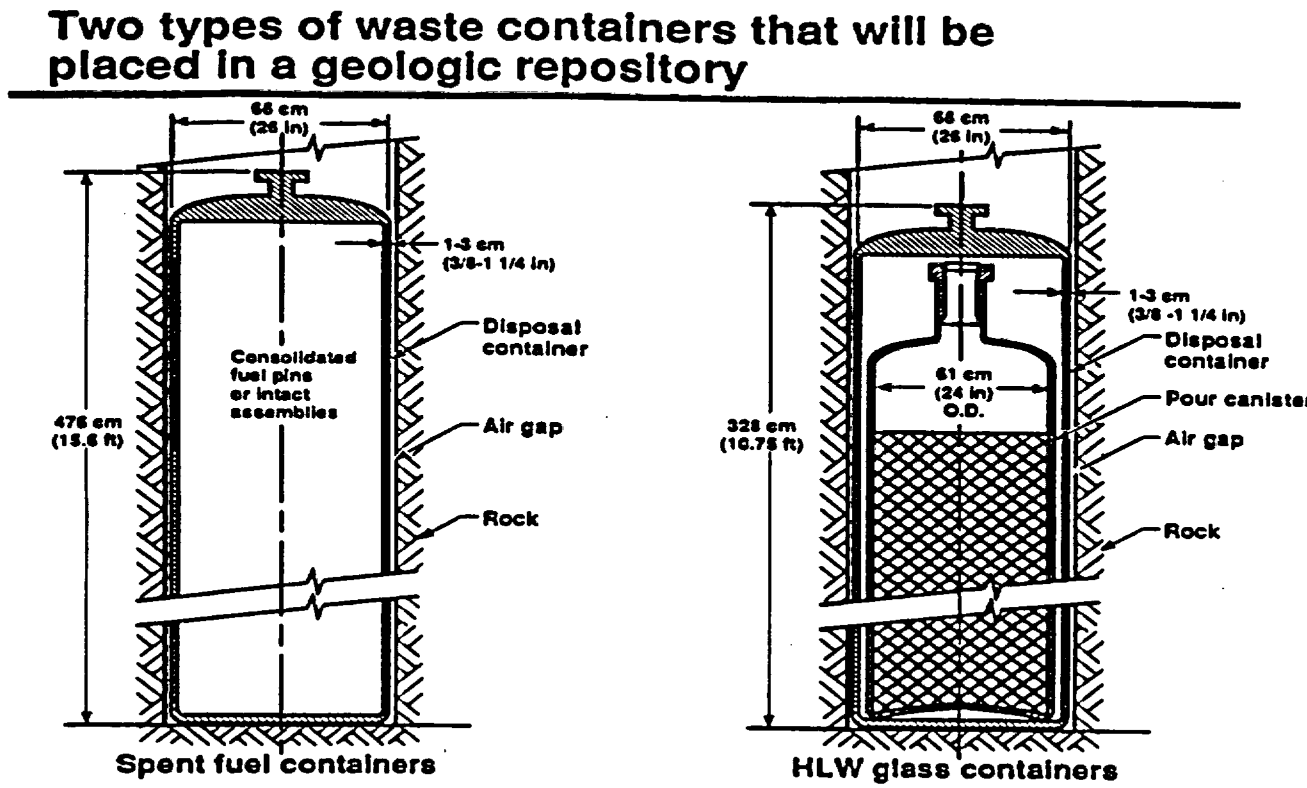


Figure 3. Spent fuel and HLW containers

control procedures, and assembly methods. The spent fuel will be present either as intact fuel assemblies or consolidated fuel rods, with or without the hardware resulting from fuel consolidation. In either case, the spent fuel pellets will be contained within the Zircaloy cladding of the individual rods. The HLW will be contained within a 304L stainless steel pour canister, which is sealed and within the disposal container.

3.2 WORK BREAKDOWN STRUCTURE

Activities of the Project are organized into a product-oriented Work Breakdown Structure (WBS). The waste package program work scope is contained primarily in WBS Element 1.2.2 as shown in Table 1.

The waste package program activities also utilize three other WBS elements that are generic and have a broad scope. Funding is derived from Systems (WBS 1.2.1) to cover systems engineering, data base implementation, waste package system performance assessments, and near-field geochemical modeling activities. Funding is derived from Regulatory Interactions (WBS 1.2.5) to cover SCP updates and regulatory interactions. In addition, funding is derived from Project Management (WBS 1.2.9) to cover quality assurance, records, Project cost and schedule control, and overall Project management. More detailed definitions of the WBS work elements are included in the Project WBS dictionary.

Table 1. Primary WBS elements of the waste package program

NUMBER	DESCRIPTION
1.2.2.1	Waste Package Management & Integration
1.2.2.2.1	Chemical & Mineralogical Properties of the Waste Package Environment
1.2.2.2.2	Hydrological Properties of the Waste Package Environment
1.2.2.2.3	Mechanical Attributes of the Waste Package Environment
1.2.2.2.4	Engineered Barrier System (EBS) Field Test
1.2.2.3.1.1	Waste Form Testing - Spent Fuel
1.2.2.3.1.2	Waste Form Testing - Glass
1.2.2.3.2	Metal Barriers
1.2.2.3.3	Other Barriers
1.2.2.3.4.1	Integrated Radionuclide Release Tests & Models
1.2.2.3.4.2	Thermodynamic Data Determination
1.2.2.3.5	Alternate Concepts
1.2.2.4.1	Waste Package Design
1.2.2.4.2	Container Fabrication & Closure Development
1.2.2.4.3	Container/Waste Package Interface Analysis

3.3 PROGRAM LOGIC AND TECHNICAL APPROACH

The program logic used to develop the waste package design will utilize the classical systems engineering approach. This logic will consist of the following sequence of steps:

a. Define waste package design requirements.

b. Develop design options to meet requirements.

c. Evaluate design options.

d. Select preferred design option.

e. Develop and engineer the selected preferred design option.

f. Verify that design requirements have been satisfied.

Due to the lack of confirmed information and data necessary for the establishment of the requirements, especially in the areas of waste form characteristics and the near-field environment surrounding the waste packages, the program will pursue an approach in which the waste package requirements will be established based on the limiting or assumed bounding values using the best information available during each phase of the program. It is expected that some more stringent bounding values will be reduced as additional data are acquired, thereby allowing the design to be refined or the margin of safety to be increased.

The steps of the systems engineering approach will be pursued in the manner illustrated by the flow diagram in Figure 4 and discussed in Section 3.3.1.

To be consistent with the repository development program, the waste package program is divided into three phases: pre-ACD, ACD, and LAD. In each of these phases, the information used is progressively better defined and has a more substantial basis. As noted earlier, this program is aimed at the primary objective of achieving a license application design which can be submitted to the NRC for approval through the licensing proceedings.

The technical approach that will be used to both contain and control the release of radioactive materials will be based on a multi-barrier approach as conceptually illustrated in Figure 5.

The illustration represents the basic components of the reference designs for the spent fuel waste package and the HLW waste package. As currently envisioned in the conceptual design, the release of nongaseous radioactive materials from the spent fuel requires the presence of water, and

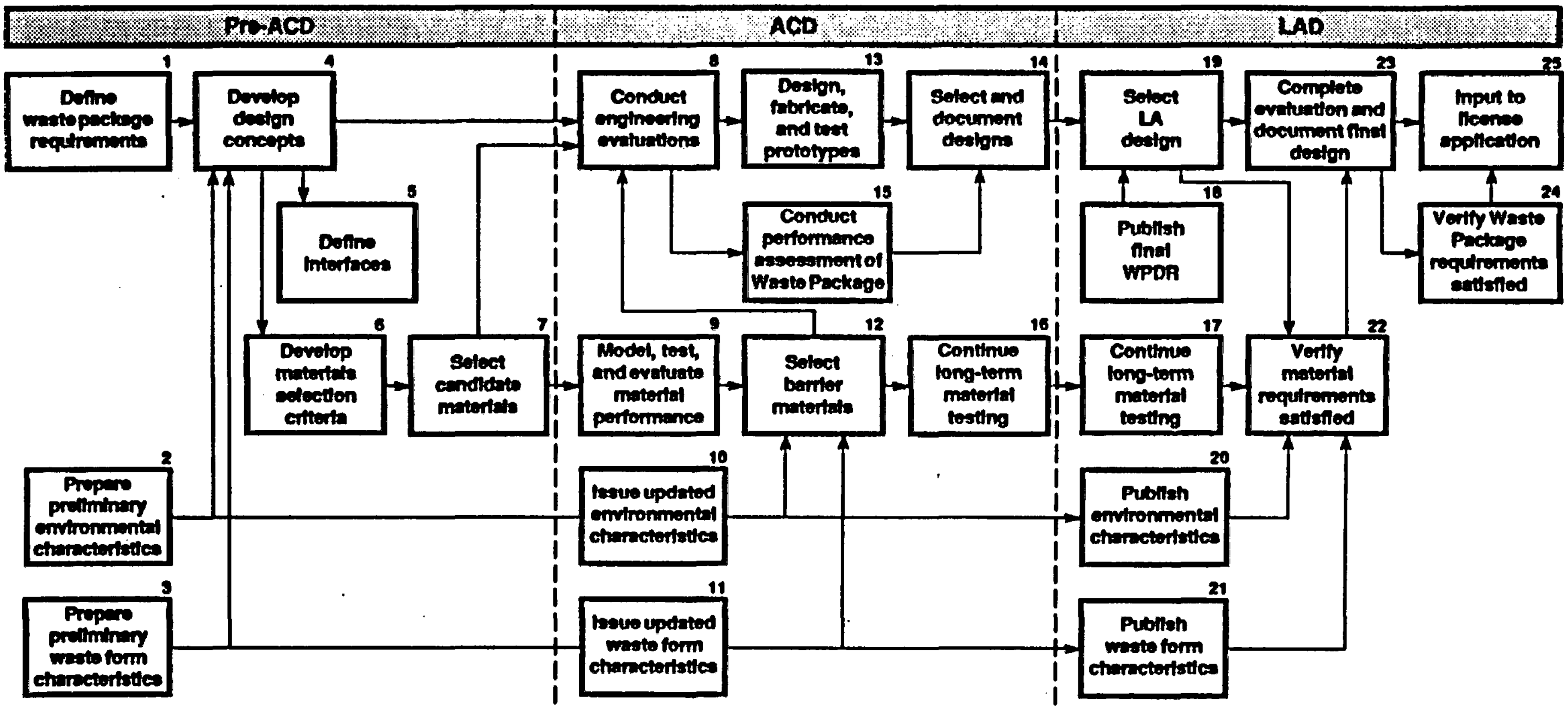


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Figure 4. Flow diagram of Waste Package Program.

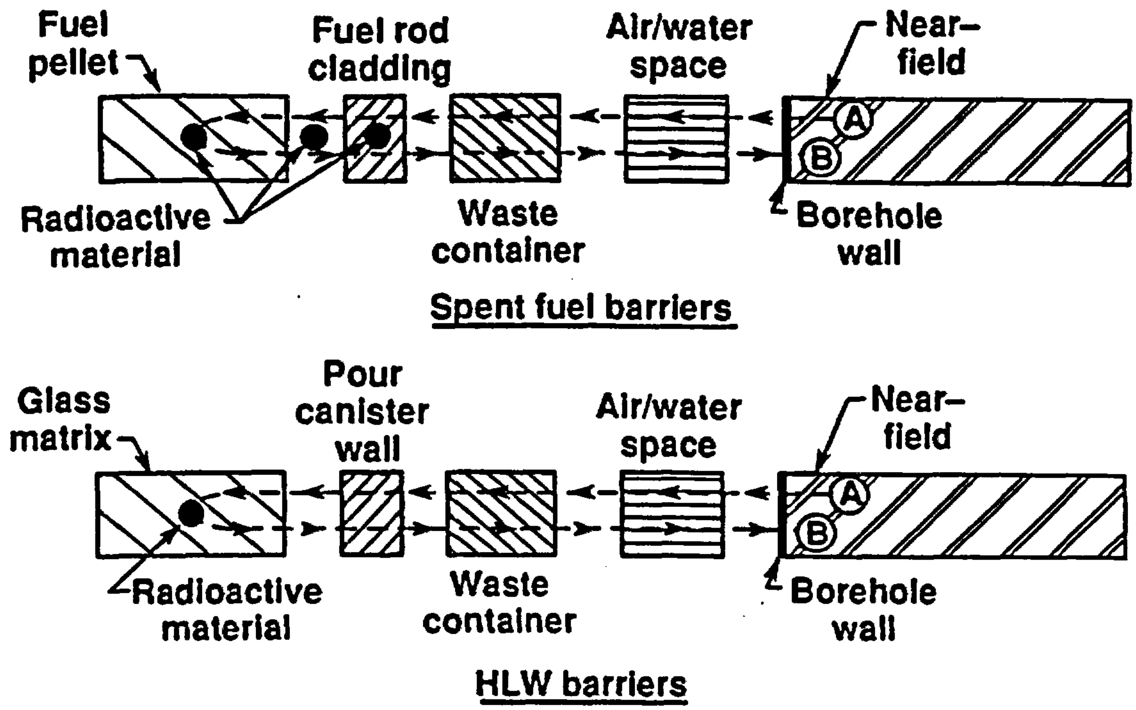


Figure 5. Illustration of multi-barrier approach.

the water must be present to provide a path (A) to (B) through the barriers for radionuclides to be released to the near field as illustrated in Figure 5. That is, the release of radioactive materials from spent fuel pellets requires the following:

1) Liquid water must be present in the air gap in sufficient quantities and for a long enough period to establish a mass transport mechanism for the nongaseous radioactive materials; gaseous radioactive materials can be transported from the container to the near-field environment without the need for water.

2) Water or water vapor must be present at the external surface of the waste container for a sufficient time period to cause a breach of the container by corrosion through the wall. The container could also fail from structural loading.

3) Water or water vapor must continue to be present inside a container for a sufficient time to cause a breach of the fuel rod cladding (a small fraction of the rods will already have cladding penetration).

4) Water or water vapor must remain in contact with the fuel pellets for sufficient time to support release of the radioactive material from the pellets, which can then be transported through the failed barriers. Some radioactive materials can also be released from the corrosion and oxidation of the spent fuel cladding and fuel assembly structural hardware.

As illustrated in Figure 5, a similar sequence of events is necessary for the release of HLW from the glass matrix and into the near-field geologic media.

The waste package program is structured to address each of these multiple barriers and to determine the amount of penetration and subsequent radionuclide transport that can be expected during the periods of concern. The program will determine the variability that may occur in the penetrations through the individual barriers. Although bounding values will be selected, a model that considers the product of the penetration distributions for the individual barriers will predict a lower release than will one that considers the product of the bounding (maximum) values.

An alternate waste package design concept will be developed and evaluated following the same program logic, technical approach, and activities as planned for the reference concept discussed above. Both concepts will be pursued into the early LAD phase; then a single waste package design concept will be selected for final design development. From that decision point in LAD, only a single selected design will be pursued through LAD. Besides fulfilling the 10 CFR 60.20 (c) (i) (ii) (D) requirement on alternative design considerations, this dual path with a reference and an alternative design concept approach is considered essential in view of the high level of uncertainty in three critical programmatic areas:

1) Actual waste package service environment characteristics.

2) Actual waste form characteristics.

3) Long term prediction capability of container and waste form material behaviors.

For example, with regard to the near-field environmental characteristics, actual data from an underground repository horizon will not be available until it is provided from engineered barrier system field test experiments and from observations made through the use of the ESF. However, the ESF will not be available for near-field environment characterization tests until the LAD phase. The waste form characteristics required for the waste package program include a substantial degree of uncertainty. Uncertainty is introduced because the spent fuel characterization data will be based on spent fuels available through the LAD dates. These spent fuel inventories are likely to be very different from future spent fuel inventories to be placed in the repository after the year 2010 because future spent fuel will be subjected to much higher burn-up levels and may have different fuel compositions. Finally, prediction of material behaviors for 1000 years or more represents a very substantial extension of the currently best available materials' behavior projection capability of approximately 50 to 100 years.

In view of these uncertainties, which are not likely to be overcome during the program lifespan through the license application, the pursuit of a single design concept would involve a very high programmatic risk. If the single design concept were somehow determined to be unsatisfactory because of updated information found late in the program or during the licensing process, the recovery time for the schedule in terms of developing a new and different design concept would, among other things, require the acquisition of long-term materials testing. Such materials testing would require 10 or more years to develop a different alternative design and confirm its adequacy through prototype testing and the application of validated models for the waste package environment. Such a programmatic delay is not acceptable. For such reasons, the two waste package designs, a reference and an alternative, will be developed through the early LAD phase.

3.3.1 OVERALL PHASING

As in the repository program, the waste package program consists of the following three phases: pre-ACD, ACD, and LAD. Activities included in each of these phases are identified and graphically illustrated in Figure 4. Although not always explicitly stated below, the same systems engineering approach is followed for both reference and alternative designs. These activities are further described in Sections 3.3.1.1 through 3.3.1.25.

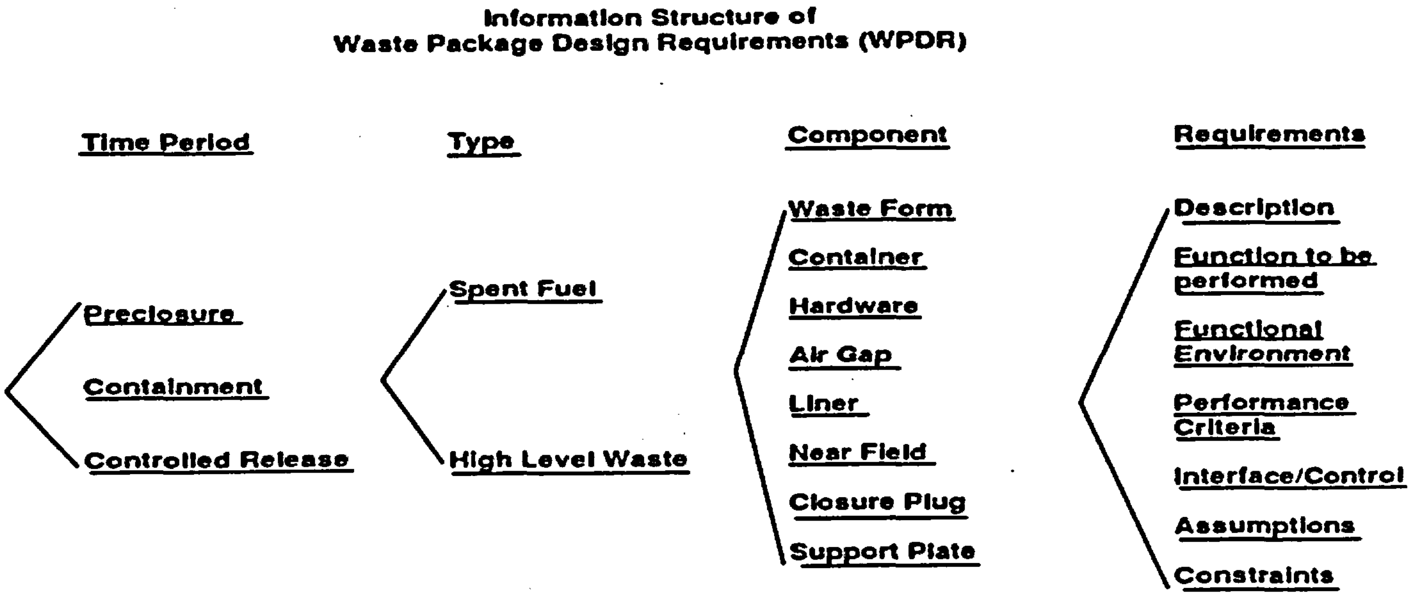
3.3.1.1 Definition of requirements

The first step of the waste package design and development process is to define and document higher-level requirements that the waste package must meet (Milestone M01 in Table A-1). The higher-level requirements will be derived directly from the various regulations discussed in Section 2.2. Next, the OCRWM Waste Management System Requirements (WMSR, Volumes I and IV) adds additional programmatic requirements. Finally, the Project System Requirements document defines a top-level allocation of the generic and site-specific requirements among the major subsystems that comprise the Mind Geologic Disposal System (MGDS), without unduly constraining design efforts of individual subsystems.

After the development of the higher-level requirements and the development of design concepts (Section 3.3.1.4), Waste Package Design Requirements (WPDR) documents will be prepared and baselined for selected concepts to establish a common basis for the wide variety of activities within the waste package program and for activities external to the waste package program that have a need for such information. The allocation of requirements to the waste package components will also be defined and documented in the WPDR. These allocations will be based on the preliminary waste form characteristics and near-field environment characteristics described in Sections 3.3.1.2 and 3.3.1.3. Table 2 illustrates the four areas that will be addressed by the WPDR.

Column 1 of Table 2 identifies the different time periods used in the waste package program. Column 2 lists the two primary types of waste forms that must be considered. Column 3 lists the various components associated with a conceptual waste package. The types of requirements in the WPDR are shown in Column 4. The WPDR will specify for each time period, for each waste form type, and for each component of the waste package the specific requirements that the design must satisfy. For example, the requirements for the waste package container for the "containment period," when its function is to serve as a primary barrier for relatively hot fuel in a relatively dry environment are substantially different from those for the "controlled release period," when the container is allocated a lesser role in restricting the release of radionuclides to the near-field geologic media.

Table 2. Items addressed in the WPDR



Development of the WPDR document will involve the consideration of waste package design elements, container materials, near-field environment, and waste form characteristics, and will necessitate communication and coordination with other Project Participants involved in both repository design and site characterization investigations. A WPDR document will be developed that is sufficiently detailed to guide pre-ACD activities and to develop design concepts (box 4 in Figure 4). Changes to the baselined WPDR will be subject to configuration management and change control procedures so that provisions are available to update the WPDR as appropriate in later design phases.

3.3.1.2 Preliminary definition of the waste package and near-field environment

Based on the best available data for the underground conditions at Yucca Mountain, the near-field environment will be defined and documented (Milestone M02 in Table A-1). This document will be baselined and used with the WPDR to develop design options during the pre-ACD phase. The environmental conditions of primary concern that will be addressed in this report are (a) hydrological (water flow and quantity), (b) geochemical (water quality), (c) thermal, (d) radiation, and (e) mechanical loading conditions associated with the near-field environmental perturbations caused from excavation and construction activities, waste emplacement, and closure operations. Characterization of the environment will be conducted through field and laboratory tests, model development, and analyses. The environmental characterization analyses will be based on currently available laboratory tests and documented data available from all Project Participants and other available sources in addition to waste package program studies completed prior to the end of Fiscal Year (FY) 90. Repository horizon samples will not be available from either surface-based testing or from the ESF. Therefore, the document will focus on general tuff environments to provide data to bound the environmental conditions. As new data are developed, they will be incorporated in the document using approved change control procedures. Details of specific activities that will be performed will be described in Study Plans and Scientific Investigation Plans.

This plan assumes anticipated environmental conditions, as used in 10 CFR 60, will be defined during the ACD phase. Prior to that time, the near-field environment activities will establish evaluations of bounding conditions of the expected environmental underground conditions present. The values of the parameters in the preliminary document will be selected to include the bounding values that quantify the near-field environment as illustrated by arrow (A) in Figure 6. It is assumed that bounding values include the anticipated conditions to be developed in ACD, and they will be used in all design and waste package performance evaluations.

It is well understood that there is a spatial variation of the environmental parameters when considering the overall repository site. It is expected that the acquisition of additional near-field site characterization data under more realistic conditions in subsequent program phases after pre-ACD will establish, for some parameters, narrower distributions and possibly shifts in the mean distribution values. When this occurs, the bounding values may be reduced to a level as indicated by (B) in Figure 6. Such a shift could enable the designer to modify the design for less severe conditions or to document and take additional credit for greater design margins.

3.3.1.3 Preliminary definition of waste form characteristics

During pre-ACD, resources will be directed to the documentation of the waste form characteristics that impact the design, development, and evaluation of the waste package and the engineered barrier system. This preliminary documentation will be based on the best information available (Milestone M03 in Table A-1). This document will ensure consistency within all the various subsystem elements. Special emphasis will be placed on the identification of characteristic parameters that will be required by the designers and evaluators of the components of the waste package and the EBS. Such characteristics include the quantities of various waste forms and the ranges of waste form ages, decay heat contents per unit mass or volume, the specific radionuclide inventories per unit mass or volume, the initial uranium-235 enrichments in spent fuel, and different types of pressurized water reactor and boiling water reactor spent fuel assemblies and associated physical properties. Additional characteristics are required for performance evaluations and performance assessments.

There are two primary types of waste forms, i.e., spent nuclear fuel and vitrified high-level nuclear waste. It is recognized that there may be "other" radioactive wastes that may be emplaced in the repository; however, unless these materials are better defined, no waste package program effort will be expended toward projecting their characteristics until the ACD phase. Details of specific activities that will be performed on all waste forms will be described in Scientific Investigation Plans.

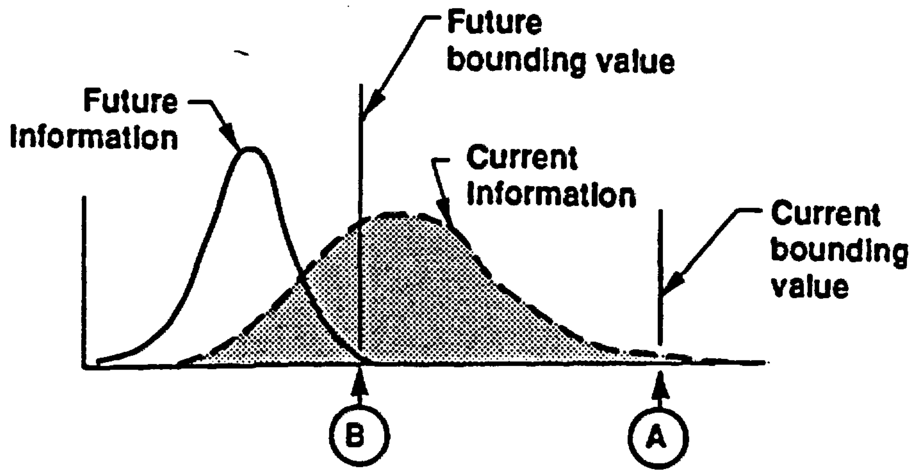


Figure 6. Diagram illustrating the use of "Bounding Values".

3.3.1.3.1 Spent nuclear fuel

The characteristics used by the designers and performance evaluators must be representative of the total inventory of spent fuel to be emplaced in the repository. The distributions of the preliminary characteristics will be estimated in pre-ACD in a quantitative form using the best information available. So that the representativeness can be established, bounding values (as discussed in Section 3.3.1.2) will be established for developing designs; subsequent in-depth investigations and analyses in later design phases will further refine the data to better develop the distributions of the variations and to establish more definitive bounding values. These initial distribution estimates will require significant refinements throughout all phases of design. Efforts will be focused on the characteristics of the spent fuel essential to the design and evaluation of the waste package and engineered barrier systems. Special attention will be given to quantifying parameters where there are near-term applications.

An evaluation will be made of how performance evaluations can deal with the fact that only a small fraction of the total spent fuel to be contained has been generated. For example, only approximately 20,000 Metric Tons of Initial Heavy Metal (MTIHM) of spent fuel exists today and approximately 40,000 MTIHM of spent fuel is yet to be generated by the utilities for the first repository.

The fuels used in the testing programs will be identified as to where they fall within the distributions developed for the ranges of typical spent fuel before detailed characterization tests are initiated. The distributions developed for projected fuel characteristics (e.g., burn-up and age), will be used to define the bounding values selected as the design basis for the waste package concepts. The waste form characteristics report will document these distributions and other characteristics (Milestone M03 in Table A-1).

Other characteristics that will be determined in the pre-ACD phase for representative spent fuel (refer to Figure 5), based on these distributions, include the following:

- o The dissolution and solubility behavior of spent fuel pellets, including the effect of air and water vapor oxidation of the UO_2 pellets and of the groundwater chemistry.

- o The fraction of soluble radionuclides existing in the fuel-cladding gap and spent-fuel grain boundaries prior to any cladding breach and thereby available for rapid aqueous release to the near field should the barriers illustrated in Figure 5 be breached.

- o The release of gaseous radionuclides from the spent fuel waste forms (i.e., spent fuel or cladding).

These latter characterizations will be performed within the bounds established and documented for the near-field environment conditions (Milestone M02 in Table A-1) and within the distributions developed for the spent fuel characteristics.

3.3.1.3.2 Vitrified High-Level Nuclear Waste (HLW)

The characteristics of the HLW that will be used by the designers and evaluators will be representative of the total HLW inventory to be placed in the repository. The establishment of these preliminary characteristics in a quantitative form will be accomplished using the best information available. During pre-ACD, distributions of the quantities and ranges of variations of characteristics, such as radionuclide content, decay heat content, radiolytic properties, and chemical composition will be established. Efforts will be made to reduce these to a form required to design waste package concepts and to conduct evaluations. As discussed in Section 3.3.1.2, bounding values will initially be established and subsequent in-depth investigations and analyses will be performed to further refine the data and to develop distributions of the characteristics that establish more definitive values. Early attention will be focused on the characteristics of the HLW that will be essential to the design and evaluation of the waste package and engineered barrier system. The preliminary HLW characteristics will include HLW data from the Defense Waste Processing Facility (DWPF) at the Savannah River Laboratory and from the West Valley Demonstration Project (WVDP). Other HLW producers (Hanford Waste Vitrification Project and Idaho National Engineering Laboratory) will quantify the chemical, physical, and radiological properties and compositions of the waste forms that they will produce, as well as Projections for HLW quantities. Such data will be used to update the waste form characteristics report (Milestone M03 in Table A-1) to the extent these data are available.

Waste acceptance preliminary specifications for DWPF and WVDP HLW glasses have been established by OCRWM. Representative prototypic samples of HLW glass based on these acceptance criteria will be used for testing. The waste producers will ensure a high degree of compliance with the final acceptance criteria via HLW production process control and some limited product sampling and analysis, as described in their respective waste compliance reports. Furthermore, representative sets of Approved Testing Materials for HLW glass will be made and an assessment will be done of the variability introduced into test results due to test method and investigator techniques.

To some extent, the HLW glass characterization testing program will be limited by the availability of representative samples of glasses. To ensure that glasses assumed in waste package design concepts and used in the testing programs are representative of the expected HLW glass inventory, distributions of parameters will be established. Based on these distributions, bounding HLW glass characteristics (e.g., glass composition and radionuclide species) will be used to define the design basis for the waste package. The waste form characteristics report (Milestone M03 in Table A-1) will document these distributions, the inventory projections, and other characteristics.

The representative characteristics of the projected HLW glass waste form inventory that will be determined include the following:

- Physical, chemical, radiological, and radionuclide properties that are representative.
- The dissolution behavior of HLW glass, including the effect of groundwater chemistry on dissolution rates and solubility limits.
- The alteration of HLW glass by a water vapor atmosphere and the subsequent dissolution behavior due to the water vapor-induced alterations.

The characterization of HLW will utilize the bounding values established in the near-field environment characterization report (Milestone 02 in Table A-1). Preliminary models that describe the processes controlling the release of radionuclides from HLW glass waste forms will be developed for use in design evaluations and waste package materials performance predictions.

3.3.1.3.3 Other Nuclear Waste

Other than spent nuclear fuel from commercial reactors and vitrified HLW, there are two other general categories of nuclear waste that may be disposed of in the repository. The first category includes relatively minor amounts of spent fuel from specialty and research reactors, commercial spent fuel fragments that have been used in test programs, and intact and/or damaged spent fuel rods from various research programs, as well as limited amounts of separated cesium-137 and strontium-90 in sealed capsules. All of the wastes in this first category qualify as high-level wastes and may be considered for disposal in a repository on a case-by-case basis. Some wastes may need further processing before being packaged for disposal. No efforts will be expended during pre-ACD to develop detailed plans for accommodating this minor category of high-level waste in the first repository.

The other category of waste that may be disposed of in a geologic repository includes all "greater than Class-C" nuclear waste. This category represents a relatively large volume of moderately radioactive waste that cannot be disposed of in shallow land-burial sites as "low-level waste." Regulations do not require that this waste be disposed of in a deep geologic repository. No efforts will be expended in pre-ACD for developing detailed plans for accommodating this waste in the first repository.

3.3.1.4 Design concept development

Based on the documented higher-level requirements, preliminary near-field environment characteristics, and preliminary waste form characteristics, a series of waste package design concepts, including functional allocations, will be developed and documented (box 4 of Figure 4). The development of the design concepts will include initial assessments of the feasibility of appropriate container manufacturing and closure processes, with particular attention to aspects that may require development beyond existing industrial practices. A report documenting the design concepts, together with a preliminary prioritization, will be generated (Milestone M04 in Table A-1). These design concepts, together with their associated requirements documents, will be used as the basis for detailed engineering evaluations during the ACD phase.

The design concepts report will include drawings and descriptions of the physical configurations, including the container and possible material options; waste form configurations; and internal and external stanchions, supports, and other emplacement configuration EBS appurtenances, including liners and shield plugs.

The design concepts will include conceptual designs for a reference thin-walled metallic container and associated EBS components as described in Section 3.1.2 and Figure 3 and other designs. The designs will be evaluated to identify variations (such as diameter changes, waste form capacities, and alternative materials) that may be appropriate for further evaluation during ACD.

A preliminary assessment of the performance of the various concepts will be conducted, using the existing container materials characterization, near-field environment, and waste form characteristics information. The purpose of these assessments is to assist in establishing a screening and prioritization of the concepts. Other aspects of the design concepts will be considered in the prioritization process, including relative manufacturing feasibility, costs, and operational implications.

3.3.1.5 Definition of interfaces

The waste package program requires the early identification and continuous management of physical and informational interfaces with other elements of the OCRWM Program. Major waste package interfaces occur between the site characterization activities, repository design, system performance assessment, and regulatory activities. At the Program level, interfaces also exist with the waste production (HLW producers, reactor operators, and spent fuel storage) and transportation activities. These interfaces define the information flow that waste package program activities either require from or provide to other program elements in support of the design, evaluation, and licensing. The boundary illustrated in Figure 1 will be used in conjunction with approved interface control procedures to identify and manage the interfaces between the waste package program and other OCRWM program elements.

Interfaces, data transfers, data, and information needs will be identified and documented in an interface report (Milestone M05 in Table A-1). Because a continuous assessment of interfaces is essential to the successful development of a waste package design, this initial interface documentation will be baselined and updated as appropriate during all subsequent design phases using approved procedures. Waste package program interfaces will be identified and managed in accordance with guidance provided in the Project Office Management Plan (Project/88-2), Systems Engineering Management Plan (NNWSI/88-3), and Configuration Management Plan (YMP/88-4), and in compliance with appropriate Project change control and other procedures.

3.3.1.6 Development of material selection criteria

Criteria for selection of the container and EBS materials to be used in the ACD will be developed and documented (Milestone M06 in Table A-1). As indicated in Figure 4 (box 6), these criteria will follow from the requirements in the WPDR and the allocation of functional requirements to the barrier components of the waste package for various design concepts. To meet the performance requirements assigned to the barrier, the container material is likely to have the greatest impact on performance. Establishment of criteria is separated from material selection because the criteria must address the functional requirements in a material-independent manner.

The selection criteria translate the functional requirements allocated to the various waste package barrier components in the WPDR into material properties and performance attributes that can be both assessed and quantified to compare candidate materials. The criteria will permit a candidate material to be judged for adequacy in meeting the allocated performance goals, and will provide a basis for a quantitative comparison to allow ranking of the candidate materials. The selection criteria will provide for comparisons of attributes of a widely varying nature. For example, issues such as mechanical properties and corrosion resistance must be compared to issues such as cost and prior engineering fabrication experience. Subjective issues, such as the expected relative acceptance of the material in a licensing process, must be considered. The selection criteria must address the uncertainties in the barrier performance goals. Because translating functional requirements into quantitative criteria requires subjective opinion regarding the type, form, and importance of each criterion, the selection criteria will be subjected to a formal peer review. The results of the peer review will be documented (Milestone M07 in Table A-1).

3.3.1.7 Select candidate materials

The selection of candidate container and associated barrier materials (box 7 in Figure 4) will be accomplished by the application of the selection criteria discussed in Section 3.1.1.6. Prior to the material selection, supporting information will be gathered, including existing data on material performance and on barrier fabrication and container closure procedures. The selection process will be conducted and documented (Milestone M08 in Table A-1) according to the approved QA program plan to ensure suitability for use in NRC licensing.

For the reference design, the candidate container materials list generated prior to FY 90 will be upgraded to be consistent with the approved QA program plan and to reflect current program knowledge. This upgrade will include a confirmation or modification of the current candidate list of six alloys, starting with the list of alloy systems established in FY 81. This confirmation will be performed by screening the alloy systems and applying the approved selection criteria. Following an initial screening process, detailed engineering studies will be conducted on a smaller list of alloys to permit a more detailed application of the criteria for selection of alloys for the ACD phase. This selection process will be supported by degradation mode surveys and laboratory testing. Failure mode models will be developed and preliminary analyses performed to support the selection. These models will be developed to address the bounding near-field environmental conditions expected at Yucca Mountain as discussed in Section 3.3.1.2. An independent peer review of the material selections process will be performed by a panel of experts from technical fields relevant to the selections (Milestone M09 in Table A-1).

3.3.1.8 Engineering evaluation of design concepts

Engineering evaluations will be conducted of selected container and associated EBS design concepts to establish their ability to satisfy design requirements and material performance requirements based on the reference sets of near-field environment and waste form characteristics. Consideration will also be given to the container and EBS manufacturing processes likely to be specified for fabrication, as well as repository procedures for closure and inspection of the waste container prior to emplacement. A variety of processes will be evaluated and the preferred design concepts will be selected and documented (Milestone M10 in Table A-1) for further design development. Preliminary structural, thermal, and nuclear criticality design evaluations will be made of the design concepts for the container and other engineered components of the waste package subsystem based on the design requirements. The results of these evaluations and the fabrication and closures processes will be summarized in a report (Milestone M10 in Table A-1). This report will include evaluations of the waste container design concepts, as well as other engineered components of the waste package (such as a borehole liners, container supports, and shielding plug) that affect the performance of the design options. The report will recommend the preferred design concepts for further development.

3.3.1.9 Model, test, and evaluate material performance

Laboratory testing of the proposed container and associated EBS materials (box 9 in Figure 4) will continue to provide data to demonstrate that the material performance is adequate and also to support the development of predictive failure models. Materials tests to be performed include aqueous corrosion, oxidation, localized corrosion (crevice or pitting), environmentally assisted cracking (stress corrosion cracking and hydrogen effects), full-scale electrochemical corrosion and stress effects, and long-term phase transformations.

In parallel with the material testing studies, mechanistic models will be developed to describe the barrier material performance. Predictive models for the 300 to 1000-year design lifetime must be developed, assessed, verified, and validated to the extent possible.

3.3.1.10 ACD update on near-field environment characteristics

In the initial ACD phase, approximately one year of laboratory testing will be completed on rock and water samples obtained from surface-based drilling activities at Yucca Mountain to further develop hydrological, thermal, and geochemical models of the repository horizon. The preliminary near-field environment characteristics report will be modified to assist in the development of the ACD through a change control process to include this information.

During ACD, laboratory testing of samples from the ongoing surface-based testing will continue. In addition, larger samples from the underground repository horizon will be available in the later ACD phase. This will allow near-field characterization testing that was not possible with the smaller-sized core from the surface-based drilling program. As the information from these tests becomes available, the baselined near-field environment report will be updated in accordance with approved change control procedures. This update will ensure information is available for models being developed in conjunction with near-field characterization tests, representative of repository conditions. Models will be developed and used to make preliminary evaluations of the near-field environmental response to waste emplacement and the impact of that response on waste package performance. Verification of codes for models will be completed prior to the application of these codes to any performance assessments. Results from underground prototype field tests will be used to begin validation of these codes for "generic" tuff, and laboratory test results will be used to begin validation of the codes for repository horizon rock.

The near-field environment report will be revised late in ACD to allow inclusion of surface-based core study results and limited information generated by large block testing (Milestone M11 in Table A-1). The ACD-phase update will be used as input for the final WPDR document.

The validation of near-field environment characterization models applicable to repository conditions will need to await the availability of in-situ data from EBS testing during the LAD phase. Emphasis during the ACD phase will be on evaluating the sensitivity of the design concept performance to various near-field environmental parameters. A study plan for the field test in the ESF will be developed for the design options under consideration. The tests will include all engineered components of the waste package system, including liners, shield plugs, and associated near-field EBS components. Possible design changes to ameliorate adverse aspects of the near-field environment on performance, or to enhance beneficial aspects of the environment, will be evaluated and incorporated into the designs during this phase (box 14 in Figure 4).

3.3.1.11 ACD update on waste form characteristics

The ACD phase of the waste form characterization will focus on the continued acquisition of waste form characteristics distributions and Projected inventory data needed for design analysis and waste package performance predictions and refinement of the models developed earlier. As the development of the ranges of variations of waste form characteristics required for design is established further, the testing program will be focused less on bounding values and more on measured distributions. Only those aspects of waste form behavior that are allocated performance in the waste package designs or that are necessary to predict waste package performance will be studied. The waste form testing program will also be reevaluated to verify that updated information about the near-field environment is being used in all waste form characterizations.

The waste form characteristics will be revised during the ACD phase using approved change control procedures as new data become available. In the later stages of ACD, it is expected that the data and models will be known with more confidence. An ACD-phase update will be issued (Milestone M12 in Table A-1) near the end of ACD and will serve as input for the final WPDR document.

During ACD, integrated models to describe the release of radionuclides from the waste packages and all of the multiple barriers illustrated in Figure 5 will be further refined. Characterizations will be conducted of the extent to which reliance can be placed on cladding as a barrier to release and the extent that UO_2 will oxidize under repository near-field conditions. In addition, preliminary models that predict the interactions between the near-field environment, container materials, waste forms, and other man-made components of the MGDS initiated during the pre-ACD phase will be further refined. A full and complete description of the complex interactions will be based upon the detailed process models that describe the behavior of the individual components as illustrated in Figure 5.

3.3.1.12 Barrier materials selection

The objective of the selection process (box 12 in Figure 4) is to choose container and EBS materials that will meet the requirements. The sets of materials selection criteria established for the selection of the material for ACD studies will be used, with any modifications resulting from improvements in the definition of requirements, changes in performance allocations, or data obtained during pre-ACD regarding the service environment, material performance, and operational issues. Any changes to the criteria will be justified and documented using approved change control procedures. The materials selection process and results will be documented (Milestone M13 in Table A-1) and used to conduct engineering evaluations.

3.3.1.13 Design, fabricate, and test prototypes

During ACD, prototypes of up to three design options will be fabricated, tested, and documented (Milestone M14 in Table A-1). The purpose of this activity is to evaluate those design details that are key to establishing the engineering feasibility of the design. The scale of the prototypes will be appropriate to the design features to be evaluated. The features will include materials properties, fabrication, mechanical handling, and inspection processes. Testing will include mechanical tests, such as impact tests, nondestructive and destructive examination of the material and of fabrication features, closure and inspection processes, and other tests as needed. The test data will be used to support the selection of designs to be carried on into LAD.

3.3.1.14 Select and document design

Based on the engineering evaluations of the design concepts (box 8 in Figure 4) and the prototype test activity (box 13 in Figure 4), two designs (one reference and one alternative) will be selected to be pursued in the early LAD phase. This initial selection process is expected to result in the recommendation of up to two reference and two alternative designs for further development until the final two designs can be selected.

The selection process will be documented in the waste package ACD report (Milestone M15 in Table A-1). The ACD report will (1) describe the recommended waste package designs at a level of detail appropriate to the ACD phase; (2) document the other designs considered and the rationale for the selection of the designs; and (3) provide the basis for proceeding with the design process into the subsequent LAD phase. The waste package ACD report will include drawings, outline specifications, a discussion of fabrication and closure processes, and estimated cost of each of the developed options; estimated performance of each option in regard to the functional requirements; references to the supporting data, engineering performance evaluation models, and model applications; description of the design selection criteria and process; and identification of the selected design options for the reference and the alternative.

3.3.1.15 Conduct performance assessment of waste package concepts

One of the primary criteria for selection of designs to be carried forward to LAD and beyond is the relative performance response during the postclosure period. The method for establishing the predicted performances will be to use waste package performance assessment codes that incorporate appropriate models of the anticipated natural near-field conditions as altered by the presence of the emplaced waste, degradation modes of container materials, and radionuclide release rates from the waste forms. During the late stages of ACD, the relationship between the bounding values being used for design and the anticipated conditions required by 10 CFR 60 will be established.

The assessments performed (box 15 in Figure 4) will be used in the selection of the ACD designs to be carried into LAD (box 14 in Figure 4) and will be documented in the ACD report (milestone M15 in Table A-1). For the developed designs, radioactive source terms will be developed for use in the total system performance assessments performed outside the scope of the waste package program. These initial waste package performance assessments will document the models and codes to be used during ACD (Milestone M16 in Table A-1). The performance assessment activities will be described in an Scientific Investigation Plan (SIP) and will be coordinated with existing integrated OCRWM and Project Office performance assessment (PA) plans. The waste package environment and waste form characteristics reports (Milestones

M02 and M03 in Table A-1) will be used as inputs to both the PA models and codes. The design concepts and container material characteristics will also be used as inputs to PA models and assessments (Milestones M04 and M06 in Table A-1).

In addition to the engineering evaluations (box 8 in Figure 4), the evaluation of the design options will use performance assessment codes. Code development, which was initiated and applied during the pre-ACD phase, will be continued during the ACD evaluation process. At a minimum, these codes consist of (1) single waste package performance code(s) and (2) source term or ensemble waste package code(s).

During design development, there will be a continuous flow of information across the interfaces between these code development activities and the materials, waste form, and near-field environmental characterization and modeling activities. The identification, quantification, and delineation of scenarios is a performance assessment activity that will be used to assist the development of waste package designs. The models, the codes, and the applications of the codes will be reviewed independently in accordance with appropriate procedures. The performance assessments will use baselined documents for the waste form and near-field characteristics. This review process helps ensure an accepted body of information from which a design option can be selected.

Uncertainties in performance become increasingly significant as evaluations of design alternatives progress. To distinguish among alternatives, increasingly detailed assessments are required. Continued and early model development, physical testing, and other data collection will help reduce the uncertainties with respect to the design selection process. At a minimum, an understanding of the impact of the uncertainties on the evaluation and selection process is required.

3.3.1.16 Continue long-term ACD material testing

The modeling and testing activities described in Section 3.3.1.9 (box 9 in Figure 4) will be continued to provide the long-term materials testing data required for development, verification, and validation of the predictive failure mode models. It is anticipated that at least five years of material performance test data are needed to provide defensible models for the licensing process and to predict performance over the unprecedented lifetimes required by the NRC regulations. Preparations for an instrumented in-situ prototype container with associated barriers for long-term testing in the ESF will also be conducted.

3.3.1.17 Continue long term LAD material testing

This activity is identical to that described in Section 3.3.1.16, except that once a final barrier design is selected early in LAD, only those tests and modeling analyses associated with the single selected design for LAD development will continue.

3.3.1.18 Publish final waste package design requirements

During all design phases, a review will continue of the impacts on waste package requirements due to NRC rulemaking, quantitative interpretations of qualitative regulatory terms and requirements, and the issuance of NRC generic technical position papers and regulatory guides. Any ensuing changes to the waste package requirements will be incorporated into the WPDR document using approved change control and configuration management procedures. At the start of the LAD phase, the final WPDR will be published for use in selecting the single design concept for the LAD (Milestone M17 in Table A-1).

3.3.1.19 Selection of license application design

After the start of the LAD phase, a selection will be made between the reference and alternative waste package design configurations for further development. The selection will be based on (1) the final published WPDR, (2) the existing near-field environment characterizations obtained from both large repository horizon block tests and from limited underground ESF EBS field test data of waste package configurations, (3) existing waste form characterization data, and (4) existing long-term container and associated barrier materials testing data. An initial step of the LAD phase is to review the design requirements and reconfirm that they are satisfied by the two design concepts developed during the ACD phase.

The verification of material requirements will not occur in LAD until after the selection of a single design configuration for LAD due to the need to await development of additional underground repository horizon ESF EBS field test data, completion of additional long-term barrier materials test data, and development of additional long-term waste form characterization data. The earlier a single design concept selection decision is made in LAD, the more the risk that the container material requirements cannot be verified. There is less risk when the selection of a single waste package configuration is made later in the LAD phase. However, the later in the LAD the single selection is made, the longer is the time period that two waste package configurations (i.e., reference and alternative) must be developed as part of the LAD phase. The actual date (Milestone M18 in Table A-1) that the selection of a single design will be made will be established at the completion of the ACD phase.

3.3.1.20 LAD update on near-field environment

During the LAD phase, laboratory testing using samples of repository horizon rock will be performed to further determine the hydrological, thermal, and geochemical near-field environment properties of Yucca Mountain. Large-scale field tests of the waste package configurations will be conducted in situ in concert with analytical/numerical modeling to determine the performance in the repository environment. Various methods, including peer reviews where appropriate, will be used to evaluate the applicability of previous laboratory and field tests using repository horizon rock. The results will be documented in the report on the near-field environment (Milestone M19 in Table A-1).

Model validation will be conducted at scales ranging from surface-based core to large-scale laboratory tests to field-scale tests. Laboratory-scale tests will be used to validate detailed process models. These validated process models, along with data from core-scale tests, will be used in constructing field-scale models of the near-field environment that will then be validated using in-situ field-scale tests. The validated field-scale models will be used to provide inputs to near-field performance assessment models and to confirm the adequacy of the LAD.

Many tests performed prior to the LAD phase and prior to access to the in-situ repository environment will be, of necessity, strongly thermally overdriven and short in duration. They will therefore perturb a relatively small volume of the emplacement environment. Because key hydrothermal and geochemical processes are very sensitive to thermal loading rates and waste package geometry, thermally overdriven subscale tests will distort important aspects of the near-field environmental response. With access to the underground environment, in-situ confirmation testing can commence at reference thermal loading rates using full-scale heaters over durations that will perturb a near-field volume extending over the scale of the significant heterogeneities. These long-term confirmation tests will be defined in study plans and will continue beyond LAD. Performance confirmation testing will evaluate the effectiveness of designs and the performance prediction activities. These validations will provide a limited number of points for validation of the predictive models. The confirmation testing will extend the data available to validate the predictive models used to evaluate waste package performance during the ACD and LAD phases.

3.3.1.21 LAD update on waste form characteristics

The distribution models and data developed and used for design and performance evaluations will be reexamined in light of updated information on the distribution of spent fuel and HLW characteristics in the inventories of Projected waste quantities. The waste form characteristics work will also begin validation of the detailed process models and test data that were developed during earlier phases for the behavior of the waste forms. A key input to the validation process will be the results of long-term confirmation tests begun during the pre-ACD phase. Additional testing will be conducted as necessary to ensure that the data used to support a license application are based on testing of representative fuel samples. The revised waste form characteristics data will be documented (Milestone M20 in Table A-1) and used to support the development of the LAD.

3.3.1.22 Verify that material requirements are satisfied

The verification of material requirements (box 22 in Figure 4) will use inputs from the final WPDR (box 18), the near-field environmental characteristics (box 20), and the waste form characteristics (box 21). The verification will be fully documented (Milestone M21 in Table A-1). Additional near-field environmental data generated after selection will be reviewed to ensure the materials selected remain verified as satisfying the requirements used in the license application.

3.3.1.23 Complete evaluation and documentation of final design

Development of the two designs from the ACD phase will continue into the early stages of LAD. Following the selection of a single waste package design (box 19 of Figure 4), that design will be fully developed, evaluated, and documented. The detailed design will focus on those aspects that will allow the final repository design to be completed and the waste package and repository performance evaluations to proceed. Once these features have been developed, a design configuration freeze will be placed on those elements.

Design details will be specified in drawings and specifications. Detailed component and assembly drawings will be prepared to describe fully all of the waste package configurations that are anticipated. The drawings will specify fabrications and closure details and all component interface dimensions and tolerances. Specifications will define material composition and properties; forming, joining, and inspection processes; and component storage and handling procedures.

Detailed supporting engineering analyses will be performed and verified for incorporation into the Waste Package LAD Report (Milestone M22 in Table A-1). The level of detail associated with these analyses will be significantly more than that required in the earlier design phases. The engineering analyses will include, but are not limited to, structural analyses of the engineered components, thermal analyses of the design for the range of variability of waste form and near-field environment characteristics, nuclear analyses to determine the radiation effects on package materials and other EBS components, and nuclear criticality analyses for as-assembled and degraded configurations. Cost estimates will be refined to reflect the additional design details and material or process specifications that are imposed at this stage of design development.

3.3.1.24 <u>Verify that waste package requirements are satisfied</u>

During the LAD phase, the selected design will be documented and verified (milestone M23 in Table A-1), for conformance with all of the waste package design requirements, as specified in the WPDR. This verification process consists of three separate, but interrelated, activities that address (1) design verification, (2) performance assessment, and (3) confirmation testing.

In addition to the verification of the design analyses by qualified individuals who did not perform the analyses, other methods will be employed as appropriate. These methods will include formal design reviews, independent peer reviews, or verification tests.

Performance assessments will be conducted to verify those aspects of the design requirements that are mandated by the regulations for time periods beyond the scope of conventional engineering analyses, including substantially complete containment for 300 to 1000 years and subsequent control of release of radionuclides from the EBS for 10,000 years following closure of the repository. These assessments will also provide the source term (i.e., the time-dependent, radionuclide-specific prediction of releases from the EBS) for use in the total-system performance assessment activity. Compliance will be verified for the design-basis anticipated processes and events. In addition, assessments of the consequences of unanticipated processes and events will be provided as required for the total system assessments. The methodologies, scenarios, analysis models, and computational codes employed for these assessments will be documented

(Milestone M24 in Table A-1). The documentation will include the methods used to identify and quantify the scenarios and the basis for discriminating between anticipated and unanticipated processes and events.

The third component of the verification process is the execution of a performance confirmation testing program, as required by 10 CFR 60, Subpart F. The confirmation testing program, as specified, is comprehensive and extends over the operational life of the repository until closure. Obviously, only a limited portion of this program can be implemented prior to the submission of a license application, and the balance of the effort is beyond the scope of this plan. Confirmation tests prior to the license application will include manufacture of prototype components to verify the specified processes for fabrication, assembly, and inspection of the engineered waste package assemblies and some in-situ field tests constructed in the ESF as soon as that facility is available. Data from these tests will be used in the license application. After repository operations are initiated, in-situ monitoring of the performance of representative emplaced waste packages in designated test areas of the facility will continue the performance confirmation testing program.

3.3.1.25 Prepare input to license application

The final output of the LAD phase will be the Waste Package LAD Report (Milestone M22 in Table A-1). This report will contain the information required for the license application Safety Analysis Report (SAR) as specified in 10 CFR 60.21(c), including (1) design criteria, (2) design bases, (3) materials of construction, and (4) codes and standards used. The LAD report documentation will contain drawings, specifications for the waste package, and other engineered components, data and models used to establish the near-field environmental conditions under which the package is to perform, data and models used to establish the behavior and radionuclide release characteristics of the waste forms, and data and models used to establish the behavior of the materials used in the container and other waste package components. The documentation package will also include the results of the performance assessments carried out to determine the performance of the design and to verify that the design requirements have been satisfied. The Waste Package LAD Report (Milestone M22 in Table A-1) will be the primary waste package source document for input to the License Application SAR.

4.0 RISK ASSESSMENT

The waste package program contains elements of programmatic, technical, cost, and schedule risks that have the potential for hindering the successful completion of the program.

4.1 DESCRIPTION OF RISKS

Programmatic risks are generally associated with actions external to the waste package program and include changes in priorities assigned to elements of the waste management system, changes in enabling legislation, changes in regulatory requirements or their interpretations, and actions by other entities that delay access to facilities or underground site data needed for testing or design development activities.

The principal technical risks arise from the unprecedented engineering service life requirements for the waste package. The requirement to predict the performance of an engineered system for hundreds to thousands of years demands that a quantitative mechanistic understanding of degradation processes be obtained and formulated into predictive, extrapolatable service life models. As required by regulations, these degradation processes must include the effects of all anticipated (as used in 10 CFR 60) environmental conditions on all components of the packages, including the waste forms, containment barriers, and other engineered components in proximity to the packages. The development of these mechanistic predictive models incurs significant technical risk because advances in the existing state-of-the-art predictive capabilities in materials sciences and related engineering disciplines are needed to achieve a sufficient defensible understanding. Risks are also introduced due to the current schedule requirements that require the final design to be developed prior to the collection of significant underground ESF test data.

Cost and schedule risks, which are usually related, exist as a result of the uncertainty in the ability to estimate the level of effort or the time required to accomplish necessary scheduled activities. The sequencing of required scientific investigations engenders additional cost and schedule risks resulting from the availability of sufficient technically qualified staff, test facilities, or equipment.

4.2 RISK MANAGEMENT

To deal with the uncertainties generated by these categories of risk, management will develop funding estimates and schedules that contain contingencies designed to mitigate the unavoidable risks resulting in attainable performance, cost, and schedule goals. The waste package program uses a system of study plans, scientific investigation plans, and lower-level planning documents in conjunction with a Project control system to assist in the management and control of cost and schedule risks.

5.0 MANAGEMENT APPROACH

Within the DOE, the OCRWM provides planning, guidance, budget, and control of the programs established by the NWPA. The Director of the OCRWM is responsible for carrying out the functions of the Secretary of Energy under the NWPA, as amended, and reports directly to the Secretary. The waste package program is authorized by OCRWM with the program execution delegated to the Yucca Mountain Project Office located in Nevada. The Project Office delegates appropriate authority to the LLNL Technical Project Officer (TPO) for management and for providing technical and scientific direction to the waste package program. The TPO has responsibility for detailed planning and implementation of all waste package program technical activities.

Figure 7 illustrates the reporting relationships for those organizations implementing the OCRWM waste package program. As shown, LLNL reports through a TPO to the Project Office Engineering and Development Division, Field Engineering Branch.

The LLNL Project management structure to carry out the technical objective includes quality assurance, Project control, Project administration and four technical engineering and scientific groups. The use of four LLNL technical groups is consistent with the waste package program WBS and the technical approach illustrated in Figure 4. The four technical groups include near-field environment characterizations, container materials characterizations, waste form characterizations, and engineering activities. Subcontractors to LLNL are used to conduct specialized aspects of the waste package program under the appropriate QA program administered by LLNL and monitored by DOE.

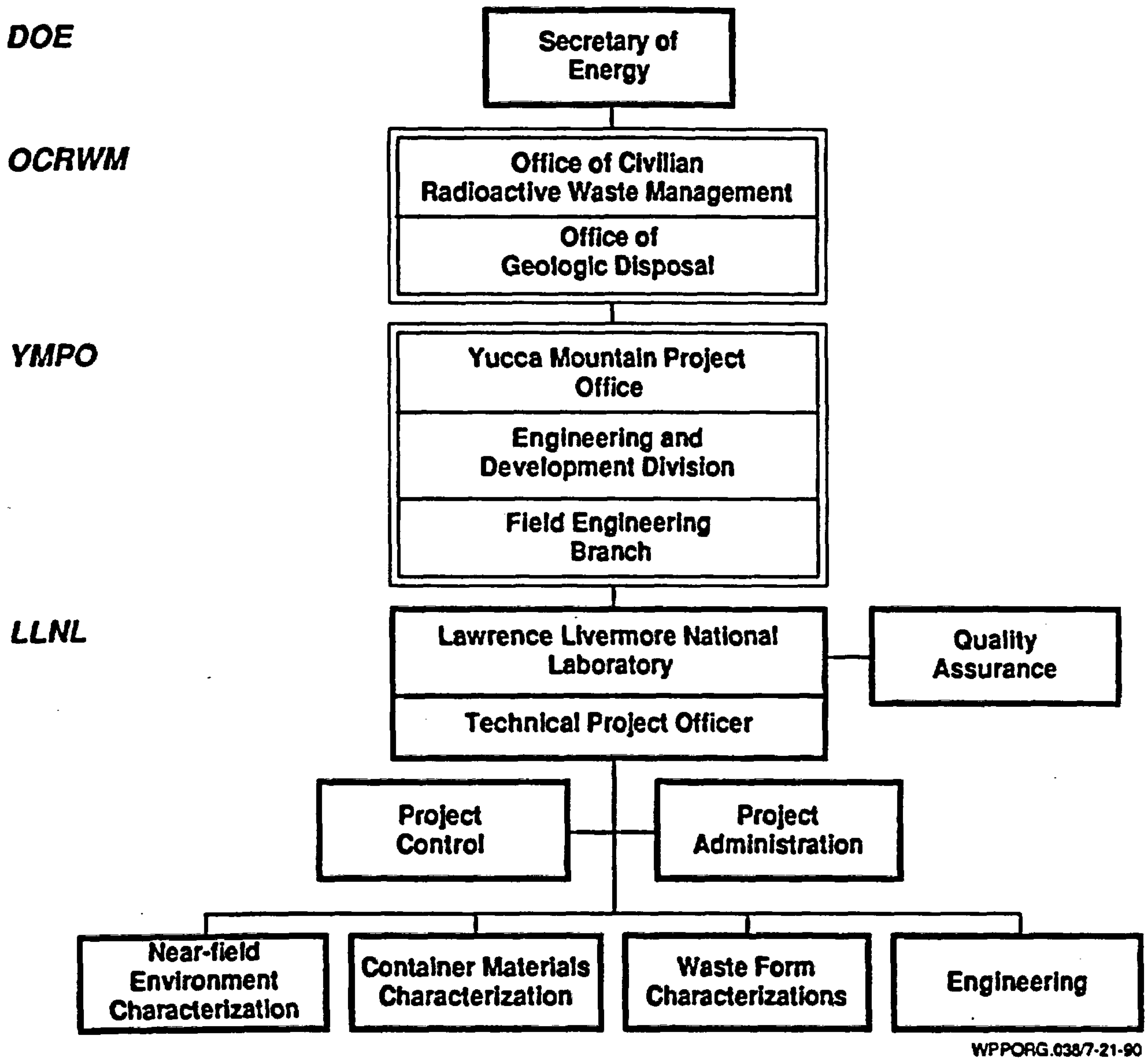


Figure 7. Reporting relationships for Waste Package Program

6.0 ACQUISITION STRATEGY

The Project Office has delegated the prime responsibility for implementing the waste package program to LLNL. LLNL is managed by the University of California through an agreement with the DOE and the DOE/San Francisco Operations Office. LLNL is responsible for conducting all waste package program design, development, and associated testing activities. LLNL, as necessary, will subcontract with other national laboratories, universities, or industries to procure the necessary technical and administrative manpower, services, and goods required to achieve the objectives of the waste package program.

7.0 PROJECT SCHEDULE

Project management systems at Project and LLNL consistent with DOE Order 4700.1 shall use an integrated system for the planning of program activities and control of cost, schedule, and technical performance through the use of a Project WBS. Planning shall be conducted in accordance with DOE Order 5700.7B, shall be based on OCRWM schedules, and shall ensure that all requirements are identified, defined, and satisfied. A summary bar chart for the waste package program is presented in Figure 8. The schedule includes significant milestones from the OCRWM or Project Office Repository Program elements for the period of 1990 through the repository license application submission in October 2001. Major milestones over the same period are shown for the four LLNL technical groups. The bar chart format is also consistent with the WBS structure and the waste package program approach illustrated in Figure 4. Table A-1 contains a tabulation of these waste package program milestones as summarized in Figure 8.* The schedule will be submitted for baseline control. Study plans, SIPs, and other technical planning documents developed by LLNL define specific detailed technical work tasks to be performed. Schedules and logic networks for the completion of this technical work and the associated resource requirements are developed and controlled using a planning and control system consistent with Project Office requirements.

* Table A-1 uses interim milestone numbers, used for reference in this plan only, which will be replaced by official baselined milestone numbers and dates.

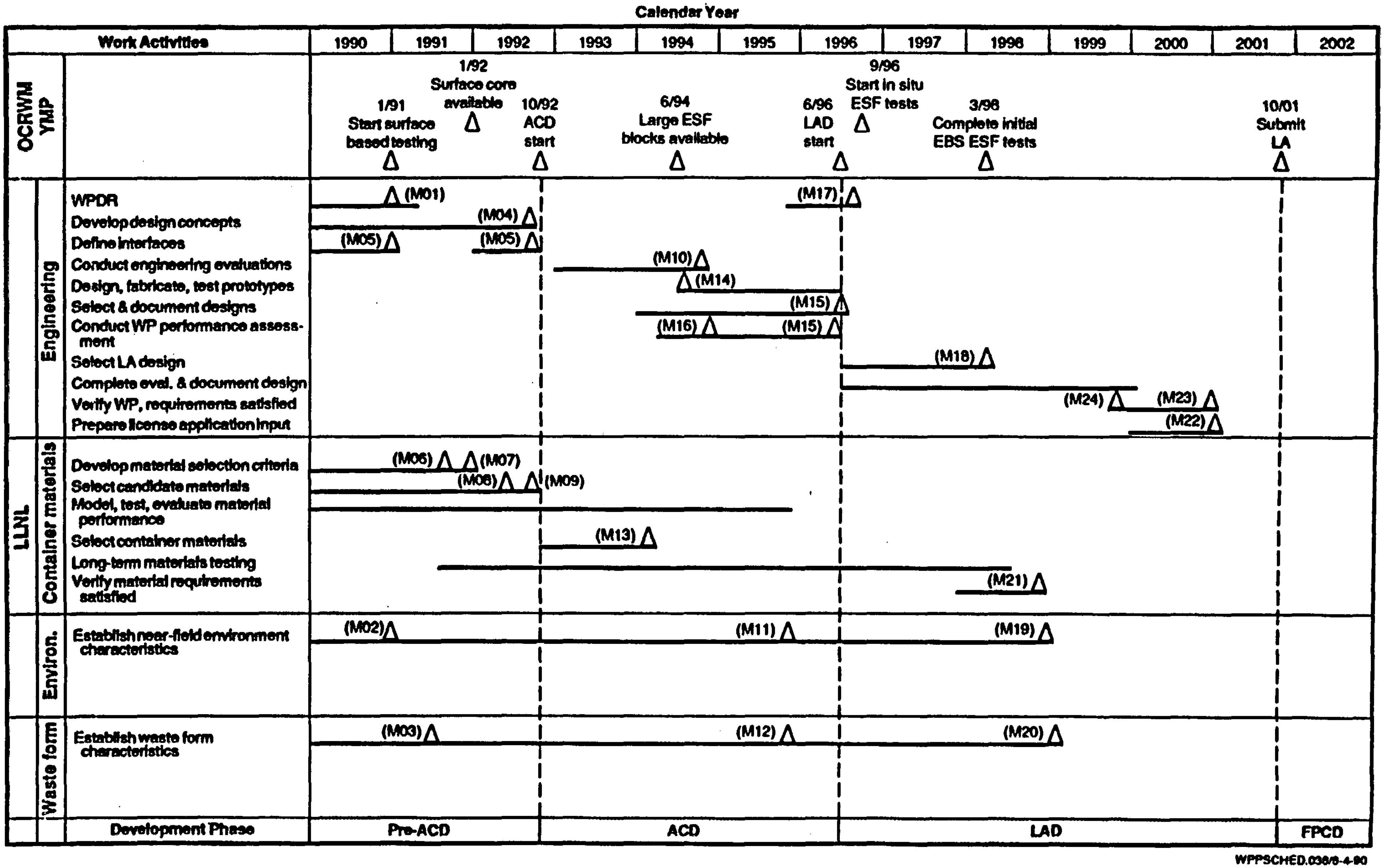


Figure 8. Waste Package Program Summary Schedule.

8.0 RESOURCES PLAN

Based on the schedule and technical planning discussed in Section 7, activities are being initiated immediately to identify resources and estimate costs required to achieve that schedule. Special attention will be directed at FY 91 and FY 92 with estimates for the out years to be developed in lesser detail. LLNL will prepare budget estimate requests to conduct the work in this plan and submit the requests to the Project Office in FY 90 for baseline control.

9.0 CONTROLLED ITEMS

The major elements to be controlled by the Project Office for DOE management reporting purposes are cost, schedule, and technical performance. The baselined schedule in Section 7 will be used in conjunction with the WBS as the key control item during each of the three repository development phases: pre-ACD, ACD, and LAD. Changes in baselined cost estimates will be addressed as variances to the baselined waste package program schedule and cost estimates. The technical work scope will be baselined using the schedule, study plans, and SIPs.

10.0 SCHEDULED DECISION POINTS

The schedule objectives defined in Section 2.2.2 and Figure 8 provide the basis for establishing key DOE and Project Office decision points in the waste package program. The program includes three phases (pre-ACD, ACD, and LAD) during which certain key decisions must be made to keep the program focused on the overall objective, i.e., development of an adequate waste package design for submission in the repository license application. The major decision points shown below are related to specific milestones in Figure 8.

Decision	Date
Identify design concepts (Milestone M04)	Prior to ACD phase (10/92)
Select container materials (Milestone M13)	Prior to LAD phase (1/96)
Select LA design (Milestone M21)	Early LAD phase (1/98)
Confirm design meets requirements (Milestone M23)	End of LAD phase (10/00)

References

10 CFR Part 50, Appendix B (Code of Federal Regulations), 1987. Title 10, "Energy," Part 50, Appendix B, Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants, U.S. Government Printing Office, Washington, D.C.

10 CFR Part 60 (Code of Federal Regulations), 1986. Title 10, "Energy," Part 60, Disposal of High-Level Radioactive Wastes in Geologic Repositories, U.S Government Printing Office, Washington, D.C.

40 CFR Part 191 (Code of Federal Regulations), 1985. Title 40, "Protection of Environment," Part 191, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, U.S. Government Printing Office, Washington, D.C.

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DOE/NV (U.S. Department of Energy/Nevada Operations), 1988. MGDS Configuration Management Plan, YMP/88-4, Las Vegas, NV.

DOE (U.S. Department of Energy/Office of Civilian Radioactive Waste Management), 1990. Quality Assurance Requirements Document, DOE/RW-0214, Washington, D.C.

DOE/RW (U.S. Department of Energy/Office of Civilian Radioactive Waste management), in prep. Waste Management System Requirements Document, Washington, D.C.

LLNL (Lawrence Livermore National Laboratory), 2/89. Yucca Mountain Project Quality Procedures Manual, 033-YMP-QP.

LLNL (Lawrence Livermore National Laboratory, 12/14/89. Software Quality Assurance Plan.

LLNL (Lawrence Livermore National Laboratory), 12/19/88. Yucca Mountain Project Quality Assurance Program Plan, 033-YMP-R.

NNWSI/88-3 Systems Engineering Management Plan.

NWPA (Nuclear Waste Policy Act), 1983. Nuclear Waste Policy Act of 1982, Public Law 97-425, 42 USC 10101-01226, Washington, D.C.

NWPAA (Nuclear Waste Policy Amendments Act), 1987. Nuclear Waste Policy Amendments Act of 1987, Public Law 100-203.

YMP-88-2 Yucca Mountain Project, Project Management Plan, 1990.

APPENDIX A

TABLE A-1. Project Office Waste Package Program Milestones.

SITE

NA	1/92	Core data available from surface based drilling

DESIGN

M01	12/90	Issue requirements per WMSR (1)
M02	12/90	Issue prelim. near-field environment characterization report (2)
M03	3/91	Issue prelim. waste form characteristics report (3)
M04	6/92	Issue pre-ACD design concepts document (4)
M05	12/90	Issue WP/EBS interface document (5)
M06	8/91	Issue barrier material selection criteria report (6)
M07	10/91	Initiate peer review of selection criteria (6)
M08	6/92	Select candidate barrier materials (7)
M09	8/92	Initiate peer review of materials selection (7)
NA	**10/92**	**START WASTE PACKAGE ACD**
M10	9/94	Issue engineering evaluations report (8)
M11	3/96	Issue updated waste package environment report (10)
M12	3/96	Issue updated waste form characteristics report (11)
M13	10/93	Issue barrier materials selection report (12)
M14	10/94	Start prototype container testing program (13)
M15	6/96	Issue waste package ACD report (14)
M16	9/94	Issue report on PA models and codes for ACD (15)
NA	**6/96**	**START WASTE PACKAGE LAD**
M17	7/96	Issue final WPDR (18)
M18	4/98	Issue preferred design option decision (19)
M19	10/98	Issue waste package environment report (20)
M20	10/98	Issue waste form characteristics report (21)
M21	10/98	Verify material requirements satisfied (22)
M22	10/00	Issue waste package LAD report (25)
M23	10/00	Verify waste package design meets requirements (24)
M24	6/99	Issue report on PA models and codes for LAD (24)

REGULATORY

NA	6/98	Provide waste package inputs to Draft Environmental Impact Statement
NA	**10/01**	**Submit repository license application to NRC**
		EXPLORATORY SHAFT FACILITY
NA	6/94	Large rock samples available for near-field tests
NA	10/96	Start EBS ESF tests

Bold entries are OCRWM milestones. Numbers in (parenthesis) refer to corresponding box numbers in Figure 4. All dates for milestone numbers with letter M are LLNL dates or LLNL dates for submission by LLNL to Project Office. Milestone numbers are used for reference in this plan only and will replaced by baselined milestone numbers.

APPENDIX B

ABBREVIATIONS

ACD	advanced conceptual design
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DWPF	Defense Waste Processing Facility
EBS	engineered barrier system
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
ESF	Exploratory Shaft Facility
HLW	high-level waste
LAD	license application design
LLNL	Lawrence Livermore National Laboratory
MGDS	Mined Geologic Disposal System
NRC	U.S. Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act
OCRWM	Office of Civilian Radioactive Waste Management
PA	performance assessment
pre-ACD	preadvanced conceptual design
QA	quality assurance
QAPP	Quality Assurance Program Plan
QP	quality procedure
SAR	Safety Analysis Report
SCP	Site Characterization Plan
SIP	Scientific Investigation Plan
SQAP	Software Quality Assurance Plan
TPO	Technical Project Officer
WBS	Work Breakdown Structure
WMSR	Waste Management System Requirements Document
WPDR	Waste Package Design Requirements Document
WVDP	West Valley Demonstration Project
Project	Yucca Mountain Project
Project Office	Yucca Mountain Project Office